Determining Tissue Damage of Fresh-cut Vegetables Using Imaging Technology

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Abstract

A method of quantitatively measuring tissue damage during fresh-cut vegetable processing was developed based on optical imaging technology. Images of damaged and undamaged tissues were acquired through a digital imaging system. The damaged areas were recognized and quantified using an Image-Pro Plus software program based on color differences of the damaged and undamaged tissues. In order to improve color differences between the damaged and undamaged tissue, the samples were stained with a 0.3% catechol solution to accelerate the browning reaction. This method was applied to determine the tissue damage of fresh-cut baby spinach *(Spinacia oleracea)* and iceberg lettuce *(Lactuca sativa)* during the centrifuge drying process. Significant differences were found among drying speeds and locations of the samples in the centrifuge drying baskets. By reducing centrifuge speed, a significant reduction in tissue damage of fresh-cut baby spinach and iceberg lettuce was obtained, especially on those located along the periphery of the centrifuge drying baskets.

INTRODUCTION

The fresh-cut fruit and vegetable industry has been rapidly expanding during the past decade, due to freshness and the high nutrition that fresh-cut produce offers, as well as convenience to consumers (Hodge 1995; Watada et al., 1996; Bauer, 1997). However, tissue damage incurred during fresh-cut processing causes rapid quality deterioration and shortens shelf life (Guerzoni et al., 1996; Watada et al., 1996). In addition to the cutting damage, centrifuge drying has been recognized as a major damaging point (Hodges et al., 2000). Centrifuge drying has been widely used in the fresh-cut vegetable industry to remove the excess surface water after washing. The impact of centrifuge drying on product quality and shelf life is two-fold: the inadequate drying that may result in fast quality deterioration and microbial growth, and the excessive drying that may cause severe tissue damage resulting in shortened shelf life and decreased production yield. It is therefore important to optimize the centrifuge drying speed and time to obtain sufficient drying while minimizing tissue damage. To do so, it is necessary to develop an easy-to-use method to quantitatively and objectively determine tissue damage during the centrifuge drying process.

Imaging processing technology has been used successfully in the food and agriculture industries in applications such as corn kernel damage evaluation (Steenoek et al., 2001; Liu and Paulsen, 2002), tomato ripening assessment (Polder et al., 2002), and defect sorting (Tao, 2000; Wen and Tao, 2000; Kim et al., 2001; Mehl et al., 2002). The main objectives of this study were 1) to develop an imaging system and methodology allowing quantitative measurement of tissue damage, and 2) to determine tissue damage of fresh-cut baby spinach and iceberg lettuce during centrifuge drying process.

MATERIALS AND METHODS

Sample Preparation

Fresh iceberg lettuce heads and baby spinach leaves were obtained from a wholesale market at Jessup, MD, USA, on the day of their arrival. Damaged leaves and other unusable leaves of baby spinach were sorted out followed by washing/sanitizing in 100 $\mu l \cdot L^{-1}$ chlorine (Na_2OCl) solution for 1 min. The leaves were then spin dried with a commercial salad centrifugal dryer (Model T-304, Garroute Spin Dryer, Meyer Machine Co., San Antonio, TX, USA) for 3 min at the tested speeds of 150 and 750 rpm. Samples from various locations including top, center, side and bottom of the centrifuge basket were collected. Triplicate samples of baby spinach, 15 g each, were weighed and placed on a photo platform for imaging. For iceberg lettuce, outer leaves and damaged leaves were removed, followed by cutting into 5 x 5 cm slices with a sharp knife. The leaves were washed in 100 $\mu l \cdot L^{-1}$ chlorine (Na_2OCl) solution for 1 min and dried following the same procedure used for baby spinach. Since the damaged areas of lettuce tissues are nearly invisible, a staining process was applied by dipping the lettuce leaves (triplicate samples, 30 g each) in 0.3% (w/v) catechol solution for 1 min followed by tap water rinsing and air drying prior to imaging by a digital image acquisition system. This staining process was developed to enhance the color difference between damaged and undamaged lettuce tissue by accelerating the natural browning reaction specifically in the damaged areas while maintaining the natural color of undamaged tissues. This enabled the identification of the damaged tissues and the subsequent analysis of damaged areas by the imaging system.

System Set Up and Image Acquisition

The image acquisition system (Fig. 1) consisted of a Nikon D1X digital camera (Nikon Corp., Chiyoda-ku, Tokyo, Japan), a Pentium PC with Windows 2000 operating system, a lighting chamber, and an IEEE1394 fire wire PCI interface (Western Digital Corp., Irvine, CA). The lighting conditions were provided by eight 15 watt cool white fluorescent lamps. The lamps were positioned at an angle to ensure uniform illumination on the photo platform without shadows in the images. The camera was white-balanced and calibrated to reflect fluorescent lighting conditions. High-resolution images of fresh-cut baby spinach and iceberg lettuce were captured by the imaging system and stored in TIFF file format for subsequent image analyses.

Image Segmentation and Analysis

The recorded digital images of the samples were analyzed with an Image-Pro Plus software program (Media Cybernetics Inc.®, Silver Spring, MD) based on color segmentation. Sample images with known damaged areas were used to train the system and set up the threshold value of Hue-Saturation-Intensity (HSI) of the damaged tissues. The damaged tissues in the follow up images were then recognized based on the HSI values obtained from the training. The total damaged areas in the images were segmented and analyzed automatically with the count/size function of the system. Pixels representing the damaged areas were recorded and used as damage index.

RESULTS AND DISCUSSION

System Calibration

To calibrate the system for damage analysis, a series of colored dots, in triplicate, of known areas were manually placed on the cut lettuce leaves to represent damaged areas. Images of the colored dots along with the lettuce leaves were recorded and analyzed by the imaging system. The total areas of the colored dots and the image pixels recorded yielded a significant liner regression with R^2=0.9976. This indicated that our system could be used to accurately measure damaged areas.

Determining Tissue Damage of Fresh-Cut Baby Spinach and Iceberg Lettuce

After calibration this imaging system was used to determine tissue damage of fresh-cut baby spinach and iceberg lettuce during centrifuge drying process. For fresh-cut iceberg lettuce, large differences in damage were found between the two centrifuge drying speeds of 150 and 750 rpm (Fig. 2). At 750 rpm, there was also a significant difference among sample locations in the centrifuge basket, with samples located near the side of the drying basket suffering much more severe tissue damage than those located at the top, the center, or the bottom. By reducing the centrifuge speed from 750 to 150 rpm, there was a significant reduction in tissue damage, especially on those located near the side of the drying basket. No difference was found in tissue damage of iceberg lettuce among various locations when the centrifuge drying speed was 150 rpm.

The damage of baby spinach followed a similar pattern as in fresh-cut iceberg lettuce, except that samples located at the bottom of the drying basket also suffered severe tissue damage in addition to those located near the side of the basket (Fig. 3). By reducing the drying speed, there was a significant reduction in damage on samples located near the side of the basket. However, there were essentially no changes on tissue damage on samples located at the bottom of the basket. Visual observations agreed with the tissue damage determined with the image results. This suggests that the damage to spinach tissues was influenced by both centrifugal force as determined by centrifuge speed and the product weight in the centrifuge drying basket. Opportunities exist by reducing centrifuge drying speed and product load in the centrifuge basket in order to reduce the tissue damage and improve the product quality and shelf life.

Overall, this method was found to be sensitive, accurate, and easy to use. It requires minimum investment on equipment (digital camera and software). It can serve as a useful tool for objective quantifications of tissue damages during various postharvest handling and fresh-cut processes.

CONCLUSIONS

A method was developed to objectively determine vegetable tissue damage using optical imaging methodology. The application of this method allowed quantitative measurement of damaged areas of fresh-cut baby spinach and iceberg lettuce and provided useful information for optimizing the centrifuge drying process to reduce vegetable tissue damage. Since tissue damage causes quality losses of fresh-cut products, this information is important to the fresh-cut produce industry in identifying opportunities to improve product quality and safety.

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Figures

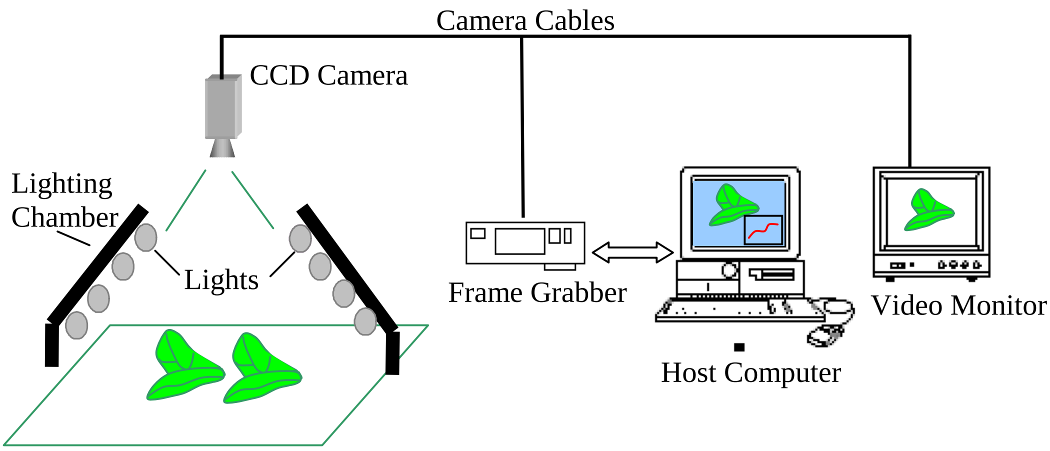

Fig. 1. A schematic drawing of the imaging system.

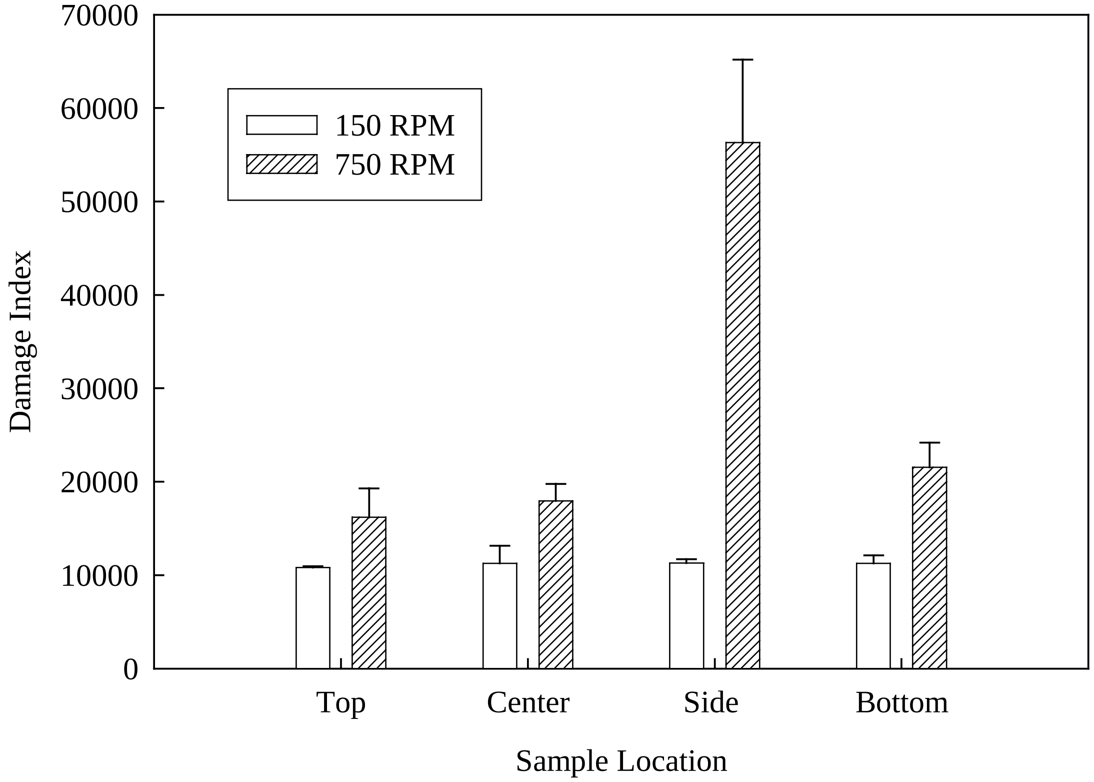

Fig. 2. Effect of centrifuge drying speed and sample location on tissue damage of iceberg lettuce.

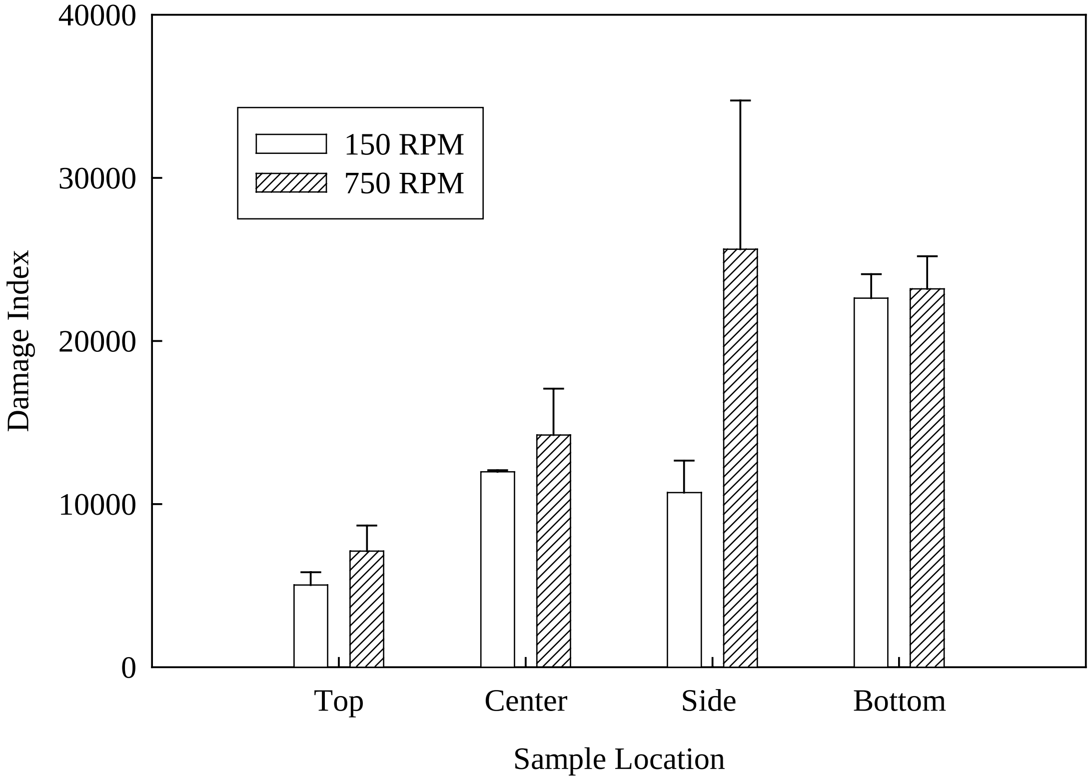

Fig. 3. Effect of centrifuge drying speed and sample location on tissue damage of baby spinach.